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CAUSES OF PERMO-CARBONIFEROUS GLACIATION

The article by David White on "Permo-Carboniferous Climatic Changes in South America" in a recent number of this *Journal* contains a discussion of the causes of that remarkable period of glaciation. One section of the article is headed, "Exaggerated Temperature Effects of Elevation"—a heading that seems to me more appropriate than the author presumably intended it to be; for the temperature effects of elevation, as a cause of the Permian glaciation of South Africa at least, appear to be greatly overrated in the argument there set forth.

It is not to be questioned that elevation of that part of South Africa from which the Permian ice sheet spread across the neighboring lower lands would have been an efficient cause of lower temperature; but at present the chief evidence of elevation is the need of it in the climatic argument; and we are not yet in the position of having so effectually excluded all other causes of glaciation as to warrant the acceptance of the elevation of the area of glacial dispersion on the ground that no other possible cause remains. It is true that the idea of great elevation of the area of dispersion was current among geologists in South Africa when I was there in 1905; but on inquiring more particularly for the evidence in favor of this idea, there appeared to be nothing more than its assumed necessity.

Two reasons are assigned by White as indicative of land elevation: "The enormous accumulations of coarse conglomeratic material in the eastern regions testify to the steep gradient of the drainage systems," and "The presence in nearly all regions of the great unconformity is itself evidence of the vigor of the post-Carboniferous uplift" (p. 631). As I see the case, neither of these reasons can be applied with force to South Africa.

As to the first of these reasons: the Dwyka tillite or glacial conglomerate of South Africa is itself the chief conglomeratic deposit of great series of continental formations in which it is the basal member; the other members are largely sandstones and shales; the Ecca formation, which follows the Dwyka more or less conformably, contains coal seams, which testify to gentle gradients, not to steep gradients in the stream systems. The great total thickness of these continental formations indicates a long-continued progressive depression of their basin, and this is quite as consistent with a long-continued uplift of never-lofty neighboring lands as with a great elevation of the neighboring lands during the formation of the Dwyka tillite.

As to the second reason: The great unconformity between the Dwyka tillite and the older formations cannot be interpreted in South Africa as meaning a vigorous post-Carboniferous uplift. The underlying deformed formations are all much older than the Dwyka, and were enormously eroded after their deformation before the Dwyka tillite was deposited upon them; hence the time of the pre-Dwyka deformation and uplift which initiated the great erosion resulting in the unconformity must have been pre-Carboniferous, not post-Carboniferous. Indeed, as far as the surface of unconformity has been traced, it everywhere shows forms of small relief; either low, well-subdued mountains, or peneplains; hence a long time must have elapsed between uplift and glaciation. Furthermore, the Waterberg sandstone of the Transvaal, supposed to correspond to the Table-mountain sandstone farther south, and surely older than the Dwyka, because it is unconformably covered by patches of Dwyka tillite, itself rests unconformably upon the eroded surface of the strongly deformed older formations, and here also the surface of unconformity is of small relief; and the Waterberg sandstone is nearly horizontal or gently inclined, thus testifying to the relative absence of vigorous uplifts in the Transvaal for a long period before Dwyka time.

Inasmuch as the Dwyka is associated with continental formations, it may have been deposited in an inclosed continental basin; and if so, it is evident that no safe inference as to the altitude of the pre-Dwyka land surface above sea level can be drawn from the small relief to which the surface had been worn down by pre-Dwyka erosion; for erosion in an interior basin may produce a peneplain at an altitude unrelated to the general baselevel of the oceans. Nevertheless, it is improbable that the interior basin of South Africa stood at a great altitude in Dwyka time; for the southern part of the Dwyka tillite follows conformably after a series of presumably continental shales and sandstones, which in turn rest conformably upon marine Devonian (Bokkeveld) strata: and it is hardly probable that the region which was low in Devonian time could have been raised to a great altitude as an interior basin in Dwyka time without interrupting the conformable sequence of stratified deposits that connect the marine and the glacial formations. True, it is possible to imagine such a case, but the imagined case includes conditions so improbable that they do not form a satisfactory ground on which to build the explanation of the Dwyka glacial climate; far less do they suffice to lead to a demonstrated explanation.

In view of all this, is it not premature to assert that "the elevation of the southern land masses" in Dwyka time is "fully demonstrated"? There certainly were times when parts of the South African land masses were deformed and elevated; but one of these times of elevation was so long before the Dwyka period that the elevated areas had been worn down to small relief when glaciation occurred; and the next occasion of strong deformation and elevation was after all the continental formations, of which the Dwyka is the basal member, had been deposited; and moreover, this elevation occurred well to the south of the area of glacial dispersion. But in Dwyka time, all direct evidence suggests that South Africa was a low-lying continental area. It is of course permissible to postulate an elevated continental area in a region concerning which we have no direct information as to Dwyka topography, north of the northernmost Dwyka tillite patches in the Transvaal; and this postulated highland may be regarded provisionally as the source of the Dwyka ice sheet; but postulating an elevation and demonstrating it are very different processes.

White says also that "the occurrence of glacial phenomena within the tropics was presumably due in part to an extension of the southern cold with the favoring assistance of ocean currents and perpetual atmospheric 'lows,' resulting in part from continental relations and topography" (p. 631). Here again, it is perfectly legitimate to postulate favoring ocean currents and perpetual atmospheric "lows," if one wishes to do so, and then to deduce the consequences of the postulates; but the value of the deductions will necessarily depend upon the validity of the postulates themselves; hence they must be examined. Ancient currents in the ocean and areas of low pressure in the atmosphere should not, in the present state of scientific inquiry, be arbitrarily assigned to this or that part of the world. The existing currents of the ocean and areas of low pressure in the atmosphere are so systematically arranged that one may fairly object to any assumed ancient distribution of these phenomena that is inconsistent with the controls by which they are determined today. For example, a continental area of low pressure in latitude 25° can occur only in the warm season, when the high temperature on the land may suffice to reverse the tendency to high pressure perpetually induced in that latitude by the processes of planetary (atmospheric) circulation; and the relatively high temperature by which a low-pressure area is formed in such a region is evidently unfavorable to the occurrence of snowy precipitation. In the cold season of the same region, when the temperature is more favorable to snowfall than at other times, the atmospheric pressure will be high, but precipitation in the area of high pressure will be small. Hence little aid can be given to Dwyka glaciation by areas of low pressure. It may be the same with ocean currents. Until a reasonable cause can be given for the occurrence of favoring ocean currents, their part in aiding the formation of the Dwyka ice sheet is only a gratuitous postulate. However satisfactory an explanation of a problem is, reached from such a postulate, it is not safe to regard the explanation as fully demonstrated until the postulate is independently established. The desirable thing in such a problem as this is the publication of diagrams, on which the distribution of lands should be indicated as described by White—"an Antarctic continent, of which Australia, South Africa, and a part of South America were possibly but lobes" (p. 630)—with a reasonable and warrantable distribution of ocean currents and areas of low atmospheric pressure in proper relation to the postulated lands and oceans. It would then be possible for a reader to judge how much favoring assistance might be expected from these contributive causes.

The Permian glacial climate is one of the most remarkable problems disclosed by geology. The addition of a South American glaciated area to the others in Australia, India, and South Africa goes far, as White points out, toward excluding any recourse to tempting explanations based on the displacement of the earth's axis. The present limitation of precipitation in at least the South African glaciated area chiefly to the warmer season, while the colder season is prevailingly clear and dry, is a difficulty that must not be overlooked. The full explanation of the problem does not involve only a moderate reduction of temperature; it involves either so strong a reduction of temperature that snowy precipitation may prevail in the warmer season, or a more moderate reduction of temperature with a change of the season of precipitation from the warmer to the cooler part of the year. Under the present understanding of atmospheric circulation, the first of these alternatives is less puzzling than the second.

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